S011
A5A3
1951

ANNUAL REPORT - 1951

CALIFORNIA
FOREST and RANGE
EXPERIMENT STATION
STEPHEN N. WYCKOFF, DIRECTOR

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE

FOREWORD

The year 1951 marked the twenty-fifth year of work by the California Forest and Range Experiment Station. In 1926 the Station assumed responsibility for forest research work which previously had been conducted by the Regional Office of the U. S. Forest Service. Cooperative relationships were established with the University of California and the headquarters of the Station were established on the campus of the University. Over the quarter century numerous projects have been carried to completion, so it is of interest at this time not only to highlight the results of the Station's work for the calendar year 1951, but also to summarize the status of the Station's program.

Research in management of timber and range resources has recently culminated in the development of some promising management systems. These have reached the stage of pilot-plant testing and demonstration. For forest management, there is a system called Unit Area Control. This system recognizes the natural units of forest stands and applies the management methods which each unit demands in order to insure full production of timber growth. It thus precludes the application of any one method to a large area of a single forest type. Pilot-plant tests of this approach to forest management have been started in ponderosa pine and mixed-conifer stands and in national forest timber-sale areas. Other tests are contemplated in Douglas-fir and redwood stands. Another pilot-plant test is being arranged to demonstrate a new system of managing mountain ranges in northeastern California. This system was developed from research aimed at reconciling the elements of practical livestock management with the growth pattern of forage plants. It differs from common range practice chiefly in the way it provides periods during which the desirable forage species are rested from grazing to build up their vegetative and reproductive vigor. Research in the foothills of the central Sierra Nevada has reached the stage at which a number of range improvement practices are being tested upon a large area at the San Joaquin Experimental Range in combination with grazing practices which previous studies on proper use of foothill forage have found most desirable.

To complement these management systems, there is now developing at a gratifying rate a realization of the necessity for classifying wild land to determine its relative suitability for such uses as timber or forage production. This realization has been greatly stimulated by the vegetation-soils mapping program developed cooperatively by the State

Division of Forestry and this Station. Under this cooperative program, the soils of some 3 million acres of privately owned land in the northern Coast Range have now been classified. The soil types often indicate clearly whether the land should be improved for forage production or should be reforested. Extension of this work to other lands in the State, improvement in survey methods, and tests to give quantitative values to yields from the different soil classes, are the steps to be expected in the future.

The Station is conducting research in methods to secure greater productivity from the brushlands of the region, primarily those in the Coast Ranges and in the foothills of the Sierra Nevada. A number of agencies are, of course, at work in this field. This Station has concentrated its effort upon research in methods of brush removal, in reseeding cleared land, and in productivity of the soil. The Station is also investigating the effect of brushland improvement practices upon runoff of precipitation, water yield, and soil stability, in order that the brushland improvement program can be based upon practices which will not jeopardize the water supplies and the top soil which are vital to the welfare of the region.

The Station's research is showing still other ways by which the productivity of the region's natural resources can be improved. Indications are becoming increasingly clear that by applying the laws of genetics to the forest crop, strains of forest trees resistant to disease and insects can be developed and more vigorous, better formed trees can be grown. Development of practices for reseeding and fertilizing depleted range lands has reached the stage at which the economic feasibility of these practices is clear. Work by the Station's forest utilization service is helping to develop improved or new methods of wood manufacturing and uses for species which heretofore have been of little or no value.

Of course much research still must be done. Changing economic and physical conditions and the development of new utilization practices constantly present new problems. Some tests require many years to complete. Often the successful completion of one research project opens the way to another, each constituting a forward step in the development of some natural resource. The Station is continuing its studies in the fields summarized here, and other activities are under way. Continued research effort by many agencies will be necessary to provide the answers demanded by today's trend toward more intensive management of wild land.

CONTENTS

The forest resource 1

Growing the timber crop 6

Protecting the forest from fire 12

Improving forest trees 18

Improving wood use 23

Growing and using the forage crop 30

Improving water yield 40

Improving watersheds for flood control 49

THE FOREST RESOURCE

According to the best region-wide figures now available, California contains about 3.5 percent of the Nation's commercial forest land and 14 percent of the Nation's sawtimber volume. This amounts to 16.4 million acres with 227.6 billion board feet of timber. Another 29.1 million acres is classed as noncommercial forest land--28.4 million acres that are of low productivity for merchantable timber or chiefly of value for other purposes than timber production, and .7 million acres that are set apart in parks and preserves. Thus 45.5 million acres, or nearly half of the State's total area is classed as forest land.

These figures are from a national reappraisal of forest resources, compiled in 1945 by the U. S. Forest Service from information supplied by Federal, State, and private agencies. The first statistically designed inventory of California forest resources was started by the Station in 1946. This project is part of the Forest Survey, a nationwide study being conducted by the Forest Service to maintain accurate, up-to-date information on the extent, location, volume, and rate of growth of forest resources, and on the drain resulting from timber cutting and losses by fire, insects, and disease.

Field Work Nearly Done On California Inventory

By the end of 1951 field work on the inventory phases of the Survey was complete for the northern Coast Range and the western Sierra Nevada. Field work for the eastern Sierra Nevada, the remaining major forest area, is scheduled to be completed in 1952. Briefly, the procedure for carrying out the inventory is to map the different kinds of vegetation on aerial photographs, determine the area of each kind, and then measure on the ground enough sample plots to obtain the needed information within specified limits of accuracy. In this work, aerial photos provide an excellent means of obtaining accurate cover maps, particularly in regions of rough topography and difficult access. It is becoming apparent, however, that because of changes in cover from timber cutting or fire, new aerial photos will be needed for future reinventories. Obtaining this new photography for the extensive forest area in California will be one of the major problems in developing the program for the maintenance phases of the Forest Survey. Preliminary discussions have been held with Federal, State, and private agencies to see if a cooperative program of aerial photography can be arranged.

Survey Reports Facts For Coast Range Pine

During the past year final computations were made, and a report prepared for publication, on the forest area, timber volume, and growth in the Coast Range Pine subregion. This is an area of nearly 10 million acres in the eastern portion of the Coast Range, from Siskiyou County in the north to Solano County in the south. Forests cover 6.9 million acres of the land, of which 3.2 million acres are classified as commercial forest land.

Timber stands of saw-timber size occur on 85 percent of the commercial forest land, with mature stands predominating on a little less than half. Two-thirds of the commercial forest area is in public ownership, chiefly national forests. Of the commercial forest land in private ownership, 58 percent is owned by companies or persons engaged in timber operation; another 25 percent is owned by farmers. Holdings of less than 5,000 acres make up 45 percent of the private commercial forest land; 36 percent is in holdings of 50,000 acres or larger.

Saw-timber volume amounted to 62.5 billion board feet (International 1/4-inch rule). Douglas-fir was the principal species, comprising 44 percent of the total volume. Ponderosa and Jeffrey pines, white and red firs, and sugar pine made up most of the remaining volume. Hardwoods, chiefly black oak, madrone, and canyon live oak accounted for 2 percent of the total. Thirty-four percent of the board-foot volume occurred in trees 41.0 inches d.b.h. and larger; 10 percent was in the 11.0 to 20.9-inch class.

The saw-timber volume determined by the Forest Survey for this subregion is approximately double that reported for the 1945 Reappraisal. This difference is partly due to subregion boundary changes, to inclusion of minor species, and to lower cull and breakage deductions in the Forest Survey estimate. The major factor, however, was the difference in the method of obtaining the volume data. The 1945 estimates sometimes had to rely on estimates for areas for which no data were available. These estimates were conservative. The Forest Survey data were obtained by measurement of sample plots selected to provide a statistically sound estimate of timber volumes throughout the subregion.

New Tables Aid Cull Estimates

One of the major tasks in any timber cruise is determining how much wood in standing trees is not merchantable because of rot, fire scar, broken tops, and other defects. This determination is particularly important in the West, where much

of the timber is mature and overmature, and hence especially susceptible to decay. In California the Survey staff has cooperated with the Division of Forest Pathology (Bureau of Plant Industry, Soils, and Agricultural Engineering) in studying ways to make reliable estimates of this cull volume. In several major species, particularly Douglas-fir, white and red firs, and redwood, the volume of cull material has been found to be closely correlated with external indicators such as conks, fire scars, and broken tops. For these species tables have been prepared showing the percentage of gross tree volume that should be deducted for each indicator. In other species, such as the pines, surface indicators are not a reliable measure of cull. For these species, other tables show the percentage to deduct from gross stand volume. These cull factors are subject to correction as additional studies are made, but the tables have been in such demand that they are being published by the Station.

Further Study Needed On Mortality Estimates

Determining annual mortality--the amount of timber killed each year by fire, insects, disease, and windfall--has also proved difficult. The Survey plan was to record on each volume sample plot the trees that had died within the preceding year. Analysis of these records showed defects in this plan. Dead trees were too spotty to be sampled adequately, and mortality too cyclic to be recorded in a one-year period. For example, the Forest Insect Laboratory (Bureau of Entomology and Plant Quarantine) has reported that losses from insect attack were ten times as high in 1931-32 as in 1942-46. Another analysis was made using mortality data from permanent sample plots maintained by several forestry agencies, and these data proved to give a better measure of mortality. For the Coast Range Pine subregion, the annual mortality loss as determined from these plots amounted to 94 board feet per acre of commercial forest land.

But mortality estimates still need to be improved. Periodic remeasurement of permanent sample plots is probably the most practicable method of obtaining reliable estimates. Since such plots have not yet been established in all the major forest regions of the State, other methods will have to be used in some areas. Meanwhile, the Survey staff is cooperating with other forestry agencies in developing an adequate network of permanent plots.

Forest Ownership Study Completed

Field work has been completed for a forest ownership study in the northern coastal counties. This study is being made

in cooperation with the Bureau of Agricultural Economics to provide answers to such questions as: Who owns the forest land? how and why was it acquired? how does the owner intend to use it? what is the condition of the timber stands? This information will provide a better understanding of forestry problems of the area. Some of the information is being published in Forest Survey reports, but the detailed findings and conclusions will be published in separate releases. Funds are not available for such a detailed ownership study in the Sierra Nevada.

Special Survey Made For Defense Project

Late in 1950 the National Production Authority requested the Forest Service to make a nationwide survey of the equipment, supplies and manpower requirements of wood-using industry. This information was needed to provide a basis for defense planning and for priority control of critical materials. This survey was made in 1951. Direction of this project in California was one of the major Forest Survey activities during the year. Personal interviews were held with 121 mill and woods operators specially selected to sample the entire industry. Detailed information was obtained on the make, size, and condition of heavy equipment, the quantity of supplies used, and the number of men employed in various types of work. The information from these sample operations was expanded on the basis of total production in each industry to provide State totals.

Besides directing the field work and computing the data for the equipment-manpower survey in California, the Station staff also compiled the detailed reports for all other western states and Alaska. This required the full time of the Forest Survey tabulating and computing force for over four months. Additional personnel were detailed to Berkeley from the Pacific Northwest and Northern Rocky Mountain Experiment Stations to help prepare the final tables.

Soil Inventory Provides Wild-land Management Tool

Since 1947 the Station has been mapping soils and vegetation on privately owned land in northern California for a project in cooperation with the State Division of Forestry and the divisions of soils in the University of California and the U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering. The State Legislature has provided funds to intensify Forest Survey mapping for this project. To conserve money and manpower during the defense emergency, the Legislature decided early in 1951 to postpone further mapping. Field mapping was halted in June, and since

then the work has consisted of preparing maps, tabulated data, and reports for publication. Funds for this work will be liquidated by the end of 1952.

Soils information from this project is more detailed than any yet gathered for large areas of wild lands. The soils are classified by depth and by standard soil series and are rated according to their suitability for timber and grass production. Samples from each series are analyzed for chemical and physical properties by the University of California. This information is valuable not only in deciding the best use of the land but also in analyzing the effects of land-use practices on flood runoff, water yield, and erosion. And a soil classification provides a sound basis for applying the results of research in land management. About 3 million acres have been covered in the Coast Range, and 2-inch-to-the-mile maps of this area are being made available for purchase. Also, timber-stand maps are being made for about 11 million acres in the Coast Range and the Sierra Nevada foothills.

All the information on soils and associated vegetation of Mendocino County is being put together in a special report, and a colored map of upland soils in the county will soon be sent to the State Printer for distribution. Covering more than 2 million acres at a scale of 1/2-inch to the mile, this map is a new departure in soils mapping.

Most maps show soil series in agricultural areas and classify the wild land soil much less intensively, often lumping them together as "rough, mountainous land." This new map lumps the agricultural soils in one class and shows detailed information for the wild lands, and thus provides more information than was previously available for wild land management. Thirty-two soil series are shown, many of them mapped for the first time. They are combined by color legend into six groups. Groups 1 and 2 are associated with conifer timber forests, Groups 3 and 4 with grass, oak-grass, and oak vegetation, Groups 5 and 6 with chaparral.

Some preliminary findings are highlighted below:

(a) Timber does best on medium-textured soils that are 4 feet or more deep to bedrock, permeable, well drained, increasingly acid with depth, and situated where annual rainfall exceeds 40 inches. Grass, in contrast, does best on finer-textured, less permeable, and less well drained soils that are between 2 and 3 feet deep and decreasingly acid or

increasingly basic with depth. Chaparral can grow on very shallow soils, less than 1 foot deep.

(b) Only the soils of Group 1 and 2 are suitable for growing conifer timber crops. As a whole these groups can grow more wood per acre than timber-growing soils of the west slope of the Sierra Nevada.

(c) The soils of Groups 3 and 4 are much better suited for grasses than those of the other groups. Relative to the very best grass sites found in the coastal counties to the south, which are rated 100 percent, Group 3 soils rate 70 percent and Group 4 rate 48 percent for grass. Groups 1 and 2 rate 24 and 16 percent and Groups 5 and 6 rate 14 and 4 percent, respectively, for grass.

(d) Of the 1,220,000 acres of soils in Groups 1 and 2, about 380,000 acres are owned by range livestock farmers; timber operators own about 345,000 acres. This large ownership by range livestock interests is particularly significant in view of the high rating of these soils for timber and their low rating for grass.

Not the least of the project's accomplishments is an increased awareness by many people of the values of vegetation-soil inventories. Vegetation-soil maps are being purchased by owners of timber, range, and other land, and by public agencies concerned with the management of wild land. Several counties have expressed an interest in having this type of survey extended to other parts of the State.

The Regional Office of the U. S. Forest Service has started similar work on the Mendocino National Forest. By July 1952 an area of about 250,000 acres, primarily in Lake County, will have been surveyed. The primary objective is to inventory basic information on soils and associated vegetation for a substantial area and demonstrate how this information can lead to sounder management of national forest lands.

GROWING THE TIMBER CROP

Production by forest industries has doubled in California since 1945: lumber production, which accounts for about 95 percent of timber utilization, increased from 2.3 billion board feet to 4.2 billion in 1950. Most of this timber is being cut from old-growth forests, and most of the Station's research in forest management was directed toward those forests in 1951.

There are other forest conditions that need study: old cut-over areas, even-aged stands of young growth, and once-forested areas now covered with brush. But because of reductions in staff--from 11 forest management technicians in 1949 to 6 in 1951--work in these areas was held to a minimum, and the men available concentrated on developing knowledge applicable to the State's 8 million acres of old growth; specifically, on how to harvest these stands so the land will be kept fully productive of tree crops.

New Approach Developed For California Forestry

Unit area control, developed by Duncan Dunning before his retirement from the Station staff early in 1951, now seems the most promising approach to the task of converting old-growth forests to managed timber stands. This concept of forest management is a product of thirty years of research in the ponderosa pine and mixed-conifer forests of the Sierra Nevada. Previous methods of management were shown not to be providing adequate restocking of pine. Analysis of records indicated that a new approach was necessary, an approach that would take into account the conditions required for optimum growth of the trees and make positive provision for new growth. Thus, the essential characteristic of unit area control is detailed control of stocking on small areas. A practical basis for classifying stand conditions has been provided. This classification gives the forester a tool to subdivide the forest into natural unit areas sufficiently small and homogeneous for uniform silvicultural treatments. For example, ponderosa pine and sugar pine, the chief commercial pines in California, are intolerant of shade and naturally occur in even-aged groups. For these species, then, unit area control aims at even-aged management by small groups of trees, in areas of from a fraction of an acre to 3 or 4 acres in size.

The basic concept of unit area control, the basis for classifying stand conditions, and the necessary silvicultural treatments have been briefly explained in a Research Note published by the Station in March. Large-scale trials of the methods used in unit area control are now of first priority to demonstrate the methods, test and refine their application, and to define more sharply what additional research needs to be done. Such trials are under way at two of the Station's field branches: the Stanislaus Experimental Forest and the Blacks Mountain Experimental Forest. In order to get additional trials of unit area control started in national forest timber sales, training sessions of one day to a week in length were held on six national forests of the region during

1951. Some sessions were attended by personnel from the Bureau of Entomology, Office of Blister Rust Control, and foresters from private industry.

Unit Area Control Tested In Mixed-conifer Stands

The first large-scale trial of unit area control was installed on 200 acres of the Stanislaus Experimental Forest in 1948 and 1949. Here special emphasis was on problems of sugar pine management. This first trial demonstrated that natural reproduction of sugar pine can be secured if an adequate seed supply is present, a suitable seedbed prepared, and rodents controlled. Seedbed or planting-site preparation, by removal of competing vegetation and slash with tractors and bulldozers, cost 22 cents per thousand board feet cut. Lower costs appear feasible and ways of reducing costs are being sought.

Prevention of logging damage is a top priority job of the forester in application of unit area control. A large proportion of the unit areas in mixed-conifer and pine stands have young trees that should be saved for future harvest. This trial demonstrated that damage to young trees can be held to acceptable standards by preparing and executing a suitable logging plan and training logging crews. How this was accomplished has been summarized for publication.

After the first cut the job of converting the virgin forest to a managed one has just begun. The forester still must encourage growth of the favored crop trees. Tests started two decades ago indicate that sugar pine crop trees can be increased by removing competing white fir. On plots re-examined in 1951, the number of sugar pine crop trees was increased from 18 per acre to 36 per acre by thinning out white fir. Much additional work needs to be done to determine the most efficient spacing between trees and frequency of thinning to maintain an adequate number of pine crop trees in the stand.

Unit Area Control Tested In Ponderosa Pine Stands

The second large-scale trial is in the ponderosa pine type at Blacks Mountain Experimental Forest, where the Station and the Bureau of Entomology have been studying methods of cutting that will forestall insect attack. Some 7,000 acres of the experimental forest were set aside for a continuous operation demonstrating unit area control techniques. A management plan has been completed for this operation and will be published to illustrate how unit area control can be used in budgeting the harvest of a ponderosa pine forest for continuous crops.

The first harvest aimed at regeneration of the stand under this plan was made in 1951, when about 5 million board feet were cut. Twenty-one acres, in unit areas varying from 1/5 acre to 4 acres in size, were clear-cut for artificial regeneration. Six acres were artificially seeded in the fall of 1951, and the rest will be planted in the spring of 1952. Seed crops occur at infrequent intervals in this type, consequently artificial seeding and planting must be used for much of the regeneration. Of course when seed crops occur, every effort will be made to secure natural reproduction.

Competition from other vegetation has long been considered a serious obstacle to securing adequate regeneration, either naturally or by artificial means. In 1948, when there was an excellent seed crop at Blacks Mountain, plots were set out to determine how competing vegetation affects natural reproduction of ponderosa pine. In 1951, seedlings had survived to the extent of 12,000 per acre where there was no competition. With a light ground cover of other vegetation, 1,500 pines per acre had survived, and 200 or less had survived with medium to heavy ground cover. In the spring of 1951 a similar test with planted pines was started. At the end of the first growing season 67 percent of the planted trees were alive where there was no competing vegetation. Forty-four percent survived with light ground cover, 29 percent with medium ground cover, and only 4 percent with heavy ground cover. These two tests demonstrate quite forcefully the need to remove competing vegetation in order to get adequate regeneration of pine.

Reasearch Started in Douglas-fir Forests

Failure of the forest to regenerate promptly after cutting is common with other species in California, and study of this difficulty has been started in the North Coast Douglas-fir forests. This work was the only new forest management study begun during the past year. Cutting in the Douglas-fir type is increasing rapidly, but there is little local information on how best to obtain regeneration. It is debatable whether the Northwest system of clear-cutting by large blocks can be applied throughout this area. Some foresters favor a selection type of cutting as a means of creating less severe site conditions and of keeping down undesirable hardwoods. Others feel that clear-cutting by small blocks may be an effective method. Finding the conditions under which each system will work best is one objective of the study.

How a forest can be regenerated should determine the

type of cutting to a large degree. To find out how well previously cut-over areas in the Douglas-fir type have regenerated, six timber-sale areas were checked. Stocking of reproduction (on a stocked quadrat basis) varied from 38 percent to 62 percent; 62 percent to 85 percent of the quadrats were covered with brush or undesirable hardwoods. Because the cutting varied so much in time and in place, no conclusions can be drawn as to the effect of intensity of cutting on regeneration.

To follow the progress of regeneration on a sale completed in 1950, seed fall was sampled in the fall of 1951. The cutting was by clear-cut blocks which varied from about 4 to 11 acres. Douglas-fir seed fell at the rate of about 280 per acre. This amount is only a few percent of what is needed for a good stand of reproduction.

The next step in this study will be to discover the conditions which favored or hindered natural reproduction on timber sale areas. The Station also plans to start work on what and how to seed or plant when natural regeneration fails; a first step here is to compare pine and Douglas-fir on various sites. Another test will seek the best ways to control undesirable hardwoods and brush.

Seeding and Planting Practices Summarized

Getting natural reproduction by proper cutting methods is, of course, most desirable. But when this fails or is impossible because of poor seed crops or other reasons, artificial seeding or planting becomes necessary. To help the man on the ground do a better job of seeding and planting, the Station summarized past research in these fields. Direct seeding trials have been conducted since about 1934 to test the effectiveness of several techniques or to find conditions under which direct seeding would or would not work. Through the years, most of the results of these tests have been reported in annual or special reports, but few were published. The results of studies were combined and summarized in Research Note No. 78, "Recent Direct Seeding Trials in the Pine Region of California." In essence the summary shows that direct seeding can be an effective method of regeneration if rodents are controlled and if seed is sown in mineral soil or ash. Placing wire screens over the seed was shown to be the most consistent means of controlling rodent damage.

One trouble with the cone- or dome-shaped-screens now in use, however, is that they are expensive to make and handle. A less expensive screen, called the "K"-screen and developed by Mr. Joseph Keyes of the Fish and Wildlife Service, is now being

window screen is better, acc. to latest info.

tested. This protective device is made from a 4-inch square of hardware cloth, rolled in the shape of a cylinder. So far, it seems to be effective against the smaller forest rodents--(mice and chipmunks). The use of poisons to control rodents is another possible method being studied. Trials of various poison baits and dispersal methods, and a study of the rodents themselves by biologists of the University of California in cooperation with the Station, suggest that poisoning should precede seed sowing by no more than a week or two and that a second poisoning may be necessary about the time that seed starts to germinate.

The summary of planting information was based on State-wide study of the causes of failures in planting. This study showed that failure resulted most often from planting in the wrong place, or at the wrong time, or in the wrong way, or with the wrong stock. Also, failure often resulted from lack of protection for an otherwise established plantation. In other words, conditions over which tree planters have some control were the chief causes of unsuccessful planting. To summarize what is known about the right conditions, a booklet entitled "Here's How - A Guide to Planting in the Pine Region of California" was prepared for field use. This booklet, written in a non-technical style, will be distributed to the men who do the planting job.

Cold Storage Tested For Planting Stock

One of the most pressing problems for planting research is that of storing and conditioning planting stock. Great climatic differences exist between the planting sites and the two regional nurseries of the U. S. Forest Service. To have trees at the right time for planting, then, means that stock must be stored. Past work indicates that stock can be stored over winter, and current studies are aimed at finding the best storage temperatures. In a study completed this past year trees stored at 0° F. for four months failed completely when planted out; those stored at 32° F. and 41° F. had 97 percent and 90 percent survival, respectively. There was no success in an attempt to condition the stock, that is, to bring it to a point where it was more ready to start growing. The procedure tested was to expose the stock to a temperature of 55° F. for one or two weeks before it was planted.

Other problems that need more study include: Nursery techniques for producing sugar pine planting stock; ways to cut down transpiration of moisture from newly planted trees; and methods of planting and seeding that are better adapted

to low-cost, mechanical means.

Ways To Forecast Mortality Sought

In the field of devising better ways to measure timber and timber products, the Station had to defer most scheduled work in order to strengthen silvicultural studies. The major job planned was to revise the alinement charts used to predict growth and mortality in forest stands. This plan was postponed, and analysis of stand mortality was pushed. It is evident that mortality is the most troublesome factor in predicting future timber yields. Not only the Station's Forest Survey staff, but also national forest administrators and industrial foresters have found mortality losses difficult to forecast. Growth, on the other hand, can be predicted within reasonable limits with the present alinement charts. Size of sample plot seems to be one key to better loss prediction, and this mensuration study will concentrate for a while on learning the minimum size of plot for a reasonable variation in loss data. Efforts to improve growth predictions--for both timber stands and individual trees--should be resumed as soon as possible.

PROTECTING THE FOREST FROM FIRE

Forest fire in California is a multi-million dollar problem. State and Federal agencies are spending about $13,000,000 a year to protect forests from fire, and damages from fire amounting to about $10,000,000 have been reported in recent years. To help reduce this bill, the Station is spending about 0.1 percent of the total for forest fire research. A Fire Research Advisory Committee, composed of top representatives of Federal, State and local governments and of the lumber industry now helps determine how these limited research dollars are used. Formation of the Committee two years ago provided a medium for exchange of ideas between research and statewide fire control personnel, and the value of this exchange is reflected in the progress made during 1951 on studies of how fires behave, the best ways to control them, and the damages they do.

Fire Behavior Linked To Upper Air Conditions

One perpetual worry of men who have the job of putting out forest fires is whether or not a particular fire is going to behave as expected. All too frequently fires explode just at the time control is in sight. Just why they do this is often a mystery, though professional fire-control men have recognized most of the

causes for some years. For example, they have known that forest fires respond to atmospheric conditions higher above the earth's surface than the heights at which burning conditions are normally measured. But fire fighters have not been able to use this knowledge as routine procedure because technicians have not yet been able to provide them with simple rules or guides.

So current research is trying to develop ways of measuring upper air conditions and correlating them with fire behavior. One phase of this work consists of analytical and experimental studies to show the kind of things that must be measured. Another phase consists of observing upper air conditions and fire behavior to provide the quantitative information needed to estimate potential fire behavior.

Several past fire situations have been analyzed. Data on fire behavior and associated upper air conditions for the severe fire situation in the Southwest in 1951 have been assembled for detailed study. Several fires there in late June and early July became disastrous conflagrations. They burned a total area of more than 100,000 acres with unprecedented speed and intensity not explainable on the basis of surface weather conditions prevailing at the time. There were indications that upper air conditions may have been a contributing cause. Completion of the analysis of this situation should add much to our present knowledge.

Future work will be aimed at perfecting ways in which these complex relationships can be made known to and usable by fire fighters.

Humidity Indicator Ready for Field Tests

The Station has just about completed development of a device that will help estimate one of the surface weather conditions that affect fire behavior. This is a humidity indicator, based on a commercial model used in packaging, which the Station was asked to test in 1950. The indicator consists of a paper card bearing a series of spots impregnated with varying concentrations of cobaltous chloride. The spots change in color as humidity increases, the point of change depending on concentration of the impregnating solution. Preliminary tests showed that the commercial models were accurate within 5 percent relative humidity but did not indicate low enough humidities for use on forest fires.

During the past year an indicator with a range of

humidity from 50 percent down to 7 percent was developed. Sample indicators used in the field during the fire season showed that humidity can be estimated within allowable accuracy under field conditions. It was concluded that these indicators can be of real value in estimating burning conditions and in correlating fire weather forecasts with burning conditions in a fire area. A humidity indicating card suitable for field use has been designed and produced for more extensive field trials during 1952. The small size, light weight, and cost of less than 10 cents each should make these indicators a helpful tool in fire control work.

Wetting Agents Found Of Limited Use On Fires

One of the continuing jobs in fire control is to be on constant alert for aids that will make fire suppression effort more effective and less costly. Several years ago the suggestion was made that wetting agents added to water, which is a recognized fire fighting tool, might accomplish both these aims. To test this suggestion, the Station first made laboratory tests to learn just what water does in putting out fire. Then plain water and water to which wetting agents were added to make "wet water" were compared in laboratory tests. This comparison suggested that wetting agents offered some advantage. Further tests were made in the laboratory and then in the field during 1951. So far, adding wetting agents to water for stopping forest-fire spread does not appear justified, though limited use may be found in mop-up work after the spread of fire has been controlled.

In the field tests, regular fire-suppression crews were equipped with tankers modified to use wet water. The tests were limited in scope by the emergency nature of fire fighting, but were sufficient to show there is no outstanding superiority of wet water for flame suppression. In mop-up work some advantage of wet water over plain water was recorded. Wet water applied to smoldering fires permitted fewer rekindles than did plain water, and hence made a saving in the volume of water used. The tests showed, however, that the same care in stirring and wetting hot fuels must be employed in either case. It was concluded that only in extra deep duff or other particularly difficult mop-up jobs could the use of wet water show significant advantages; and then only when the best known application techniques are employed. For the time being research with wetting agents will be limited to determining their physical properties and observing the performance of wet water in the course of other studies.

Booklet Tells How To Fight Fire With Water

Developing more efficient methods of using water is one of the most urgent jobs for research. Water has long been an important forest fire fighting tool. In recent years all rural fire fighting agencies have greatly expanded its use, through acquisition of large numbers of tank trucks, portable power pumps, and backpack hand pumps. Experience has demonstrated that much of the water applied to fires from these units is wasted because of the use of poor application techniques and poor nozzles.

As a first step in reducing this waste, the Station has prepared a training manual summarizing current knowledge on use of water. Information was drawn from laboratory studies of the way water puts out fire, from comparison of different types of nozzles to determine their spray patterns, and from the conclusions of men with long experience in fighting fire with water. Principles of water use for forest fire fighting were compiled from this information and published in a training manual "Water vs. Fire."

For the 1951 field study of wetting agents for fire suppression, three tank-truck crew units in California were given intensive training in these principles. The crews were also provided with special nozzles better adapted to forest fire fighting than those generally available to other equivalent tanker crews. Recorded observations of the fire-fighting performance of these three crews showed very large advantages to be gained from the use of nozzles and techniques best suited to the job and from intensive training of crew members. Therefore, research effort in 1952 will be concentrated on the development of training methods, and visual and mechanical aids that will help teach all water-using fire fighters the best known techniques. The next step will be to determine the kinds of water spray and pattern best suited to different forest fire conditions to provide the basis for designing improved nozzles.

New Index Shows Yearly Fire Severity

To test the efficiency of fire-control organizations, costs and accomplishments must be weighed each year. These analyses help point out good and bad practices and provide guides to better performance, but interpreting the analyses correctly requires some measure of the comparative severity of different fire seasons. An improved yardstick was developed in 1951.

Measured daily fire danger and area burned were

analyzed for the period 1945 to 1950 on California national forests. First, the average acreage actually burned per day of a given fire danger was computed. Then the number of days in each fire-danger class was multiplied by the acres burned per day of that class. The sum of these products was used as the index of fire severity for the year. By this yardstick the 1950 fire season in northern California was 1.40 times as severe as the 1945-1950 average. 1945 ranked second with a rating of 1.25. In southern California 1950 was rated as 0.78 of the average. 1948, the peak year, was 1.89 times the average.

The same index was also applied to local fire danger rating areas within the national forests. This comparison showed that the variation between fire seasons was not uniform over the region as a whole. Some areas showed a decrease in severity while others showed increases. Because the sample areas were too few to define the trends and causes of variation between areas, future work will extend the analysis to include additional local areas and data for the 1951 fire season.

Chemical Sprays Reduce Costs on Firebreaks

Chemical control of vegetation now appears to be a practicable way of reducing costs for one job in fire prevention and control--the task of maintaining the firebreaks, roads, and trails necessary for forest protection. This has always been a costly and time-consuming job because of the rapid regrowth of vegetation, and the Station has long searched for more effective and less costly maintenance methods. In recent years the search turned to chemicals proposed for possible use as vegetation killers. Test plots were established in a wide variety of vegetation. These plots were treated with different kinds and amounts of chemicals and watched to see which plant species were controlled by the different treatments. After a satisfactory chemical was found for a given condition, field-scale pilot tests were made to determine the operating techniques and the basis for estimating project costs.

By 1951 it was apparent that by spraying vegetation with esters of 2,4-D and 2,4,5-T, roadside brush-control costs can be reduced to a fraction of the costs for mechanical control methods previously used. From the results of plot and pilot tests, a State-wide program of brush control was recommended for national forest roads and trails and a field manual describing how to carry out this control program was prepared in cooperation with National Forest Administration. Because chemical control of vegetation is a

rapidly developing field of research, the Station plans to continue these tests, trying new chemicals as they are produced, and perfecting operating techniques.

Fire Damage Studied In Northern Forests

Some progress has been made in developing methods of appraising the damages caused by forest fires in northern California. Information of this kind is needed to plan the organization, facilities, and finances required to provide adequate protection from fire. Damages from past fires must be appraised to evaluate the effectiveness of the past protection effort. Estimates of potential damage are also necessary to distribute fire control resources so as to provide the best possible use of the protection dollar. A study completed in 1948 developed methods of estimating fire damage in the national forests of southern California, where mountain areas are used primarily for water yield and flood protection. The study now under way for northern California differs, however, in that it aims to develop principles and methods of universal rather than only local application. Furthermore a greater number of land uses and consequently greater number of forms of damage make the appraisal more complex in northern California. Also, a larger area is involved, climatic variations are greater, and hydrologic data are generally lacking for the north.

As a first step in breaking down this complex problem, the recognized forms of damage have been grouped into seven general classes:

1. Damage to the range resource
2. Damage to the timber resource
3. Damage to watershed values
4. Debris and siltation damage
5. Damage to water use and supply
6. Damage from fire suppression activities
7. Damage to recreation values

These are not necessarily listed in order of relative importance. Insofar as possible, each of these classes of damage is considered separately in developing appraisal methods. It is recognized, however, that more than one, and perhaps all classes of damage can occur on a single burn.

A tentative plan for appraising damage to the range resource was completed and tested for workability in a hypothetical problem. Desirable modifications of methods suggested by this test are being incorporated in the plan,

and a tentative plan prepared for appraising damage to timber resources.

During 1952 emphasis will be on methods of measuring the effect of fire on runoff and erosion. Information on this aspect is basic to appraisal of damage to watershed values. It is perhaps even more important in appraising site damage--reduction of the capacity of land to produce timber, forage, water, and other products. In the last two years progress has been made toward development of a method for evaluating the erodibility of watersheds through a rating of their physiographic features. Field studies of erosion on burned areas have also been made through the establishment and measurement of erosion plots and debris basins.

Effects of salvage logging of burned areas on erosion and site damage will receive particular attention because some of the plots have indicated this effect is of considerable importance.

IMPROVING FOREST TREES

Many factors that affect financial yield from timber growing are properties of the trees themselves--rate of growth, reproductive capacity, and resistance to diseases and insects, for example. These properties can be improved genetically and forest yields increased, as has been done for most agricultural crops. So far, about 70 different hybrid pines have been produced as a result of the Station's research in forest genetics. Crossing has caused striking alterations in such properties as diameter and height growth, root development, stem taper, length of foliage, and resistance to drought, frost, disease, and insects. Progress has been greatest in four groups of pines: The white pines, the western yellow pines, the southern pines, and the lodgepole-jack pine group. And there are other signs of progress, in selection studies of disease-resistant pines, in field tests of improved trees, in fundamental studies of the relationship between pine species, and in production of hybrid seed.

New Crossings Made For Pine Breeding

Each year new hybridizations are made to learn which species will cross and the ease or readiness with which they cross. Seeds collected from these crossings are planted in the nursery. If a hybrid shows promise there, the cross is repeated on a larger scale to check the original results and to produce stock for further tests.

Crossings that fail are repeated on a small scale, using different parents, to check the original result. In 1951, the Station's tree breeders made 302 controlled pollinations for the pine hybridization program. Seventy-one of them were new crossing attempts; the remainder were replications to confirm previous results or to produce hybrids for further testing. Seed from these pollinations will mature in 1952.

Pollinations made in 1950 yielded about 34,000 sound seed in 1951. Most of them were from two yellow pine crosses which have shown promise in tests at the Institute of Forest Genetics, near Placerville. One is a backcross, using the hybrid between Jeffrey and Coulter pines as the pollen parent and Jeffrey pine as the seed parent. Tests conducted by the U. S. Forest Insect Laboratory show this hybrid to be resistant to the pine reproduction weevil which kills young Jeffrey and ponderosa pines in California. The other is a hybrid between ponderosa pine of California and the Arizona variety of ponderosa pine. This hybrid slightly outgrows ponderosa pine in height at the Institute. Seed from these two crosses will be used for test plantings in California national forests.

Most of the seeds from the white pine crossings resulted from attempts to obtain blister rust-resistant hybrids. These attempts used as one of the parents either trees of rust-resistant Asiatic species or trees selected for rust resistance among American species. Dr. A. J. Riker and his co-workers at the University of Wisconsin made possible the crossings with resistant trees of American species by supplying pollen of such trees found in Wisconsin.

Twelve crossings not previously made at the Institute of Forest Genetics were included in the 1951 seed collection. Among the yellow pines there were:

Seed parent		Pollen parent
Jeffrey pine	x	Apache pine
Jeffrey-Coulter hybrid	x	Coulter pine
Slash pine	x	Longleaf pine
Shortleaf pine	x	Longleaf pine
Loblolly pine	x	Longleaf pine

Among the white pines:

Seed parent		Pollen parent
Mexican white pine	x	Himalayan white pine
Limber pine	x	Himalayan white pine
Sugar pine	x	Himalayan white pine
Western white pine	x	Limber pine
Western white pine	x	Sugar pine
Western white pine	x	Korean pine
Eastern-Himalayan hybrid	x	Himalayan white pine

These seeds will be tested for hybridity in the 1952 nursery.

Rust Resistance Studied In White and Yellow Pines

Most selection work during 1951 was aimed at production of white pines which will resist the blister rust disease. This work, part of an international research program, is conducted in cooperation with many agencies, particularly the Division of Plant Disease Control, Bureau of Entomology and Plant Quarantine; the Division of Forest Pathology, Bureau of Plant Industry, Soils, and Agricultural Engineering; the University of Wisconsin; and the Department of Lands and Forests, Province of Ontario, Canada. These cooperators furnished the Station with shoots from selected blister-rust-resistant trees of western white pine, eastern white pine, and sugar pine. These scions have been grafted on pine seedlings at the Institute of Forest Genetics. Pollen obtained from catkins on the oldest of these grafts has already been used in controlled pollinations. The aim is to produce a large supply of pedigreed resistant planting stock for study of the genetic behavior of rust resistance among white pines. Altogether 215 grafts have been established, representing 7 trees of eastern white pine, 36 of western white pine, and 2 of sugar pine--all selected for rust resistance in heavily infested stands.

How disease resistance behaves in inheritance is also being studied among yellow pines. This research, conducted jointly with the Division of Forest Pathology, BPISAE, is concerned with Cronartium harknessii, a rust that attacks ponderosa and other yellow pines. Seed obtained from controlled pollinations between ponderosa pines selected for different degrees of infection by the rust will be planted in a progeny test.

Few selection tests have been started so far chiefly because exceptional trees have been hard to find, but also because such trees have been (a) poor flower producers, (b) located far from the Institute, (c) exceedingly difficult to

climb for controlled pollinations. As more exceptional trees are found, this work will assume increasing prominence in the pine breeding program.

Hybrids Planted For Field Tests

Field tests of hybrids and other pedigreed trees are conducted to determine their tolerance to various climates and soils, and to compare their performance with that of parent species and trees native to the region. This information is needed to determine the economic possibilities of the new trees. Also, the information will enable geneticists to breed trees for particular localities with greater precision. Because of the many forest regions that must be sampled, field testing must be carried on in cooperation with others. There is no dearth of willing and competent cooperators. Scores of letters expressing eagerness to participate in this work have been received from many parts of the world. Indeed, the capacity of the Station to produce trees in excess of experimental needs is grossly inadequate to accommodate all these requests.

In California alone, 22 field tests were established in 1951. Twelve of these were at the Institute of Forest Genetics. These tests included 8 new hybrids, 3 comparisons of different pedigreed trees, and comparison of inbred seedlings with normal seedlings from wind pollination. Five tests set up in the Lake Valley Ranger District of the Eldorado National Forest included 3 hybrids. Tests of 3 hybrids were established on the Castro Valley Ranch near Gilroy, and of 2 hybrids on the San Dimas Experimental Forest near Glendora.

A branch arboretum, intended principally to grow pines which do not thrive in the Eddy Arboretum at the Institute, was established near Wrights Lake at an altitude of 7,000 feet in the Eldorado National Forest. These plantings include some rooted cuttings from the same seedlings which furnished cuttings for comparative plantings at the Institute (2,700 feet elevation). This makes possible a precise comparison of the effect of different environments on a single hereditary type.

Biochemistry Shows Pine Relationships

Biochemical analysis of pine turpentines, now nearing completion, has contributed to the progress in pine breeding. This systematic survey of oleoresin chemistry of the genus Pinus was undertaken by Dr. N. T. Mirov several years ago. Study of the distribution of

chemical compounds in a complete taxonomic group of plants promised contributions to knowledge of plant evolution, plant breeding, and chemistry. This promise has been realized.

The results have established chemical analysis of oleoresins as a means of distinguishing between pine species. Several new chemical compounds have been discovered. Chemical analysis can be used as a routine diagnostic aid in the study of insect resistance of natural and artificial hybrids. Oleoresin specificity also suggests that the resistance of certain pines to a species of bark beetle may be related to the chemical composition of oleoresin. This may well prove to be a very fruitful hypothesis; and the U. S. Forest Insect Laboratory proposes to test the hypothesis in the course of its studies of resistance of certain hybrids to insects that attack one or the other of their parental species. Results of these oleoresin studies have already proved helpful in making a taxonomic revision of the genus, and doubtless they will be found useful in other ways.

This work recently received impressive recognition in the form of a $10,000 grant from the Rockefeller Foundation made to Dr. Mirov through the University of California to enable him to complete the over-all study of the genus in the next two years. It is worth observing that when these studies were proposed, no specific application of their results could be put forth in justification. Yet some very important applications have already been found and the end is not yet in sight. These circumstances have been true of many other fundamental investigations. In the words of Francis Bacon, they are "experiments of light" rather than "experiments of fruit." Yet in the long run they are often by far the more fruitful.

Taxonomy Revision Aids Pine Breeding

One of the major aids to forest geneticists developed during the year is a regrouping of the pine species to guide crossing programs. To avoid waste of effort by indiscriminate crossing, forest geneticists set up priorities favoring crossings most likely to succeed. Heretofore, these priorities at the Station have been based on G. R. Shaw's taxonomic classification of the pines. Results of the species-crossing program and biochemical studies indicated that this classification was not sufficiently refined to give the kind of guidance that is needed. Dr. J. W. Duffield has proposed a taxonomic revision based mostly on the Station's experimental results. This revision will hereafter be relied on for guidance in setting up hard pine

hybridization. This is but the first step in a series of revisions that will be based on information to be obtained from hybridization, biochemical, morphological, and other fundamental studies. The first revision will be published soon.

Study Seeks Greater Hybrid Seed Production

Possibilities of speeding the application of experimental results were indicated in the field of mass production of hybrid seeds. Two recognized methods of mass production are by hand pollination of conelets protected by bags and by simulated wind pollination (dusting pollen from a controlled source on isolated trees). High seed yields per bag were obtained from some hand pollination in the 1951 harvest. But more information is needed on yields from hand pollination in years of abundant conelet production, and more tests are needed of techniques for simulated wind pollination. Other methods of enhancing seed production, including stimulation of flower production, are being investigated.

IMPROVING WOOD USE

Another way of increasing financial yields from timber growing is by making better use of the wood now being grown. In this field, the Station maintains a two-man unit known as the Forest Utilization Service. This unit searches out the wood-using problems of the California region, refers these problems to the U. S. Forest Products Laboratory or other agencies for research, and brings the results to local industries, wood users, and timber growers.

Small-Sawmill Methods Shown to Foresters

Because lumber is the main forest product in the region, much of the Station's work in wood utilization is aimed at improved lumber manufacturing practices. During the past year, a start was made on improving lumber production by small sawmills, that is, mills with annual production of less than 10 million board feet each. These are becoming an important segment of the lumber industry. From 1940 to 1948, production by larger mills increased from 1.7 billion board feet to 2.5 billion, or 45 percent. Production by the small mills increased from one-fourth billion board feet to 1.5 billion, a gain of 504 percent. This trend is likely to continue, as it has in older lumbering regions of the Nation. It is therefore important that the small mills manufacture lumber efficiently to

maintain a thriving lumber industry in California.

To help in this task C. J. Telford, a small-sawmill specialist of the Forest Products Laboratory, in 1950 made a survey of sawmill practices in the pine-producing region, centering around the Tahoe National Forest. This prepared the way for a small-sawmill demonstration held by the Station, National Forest Administration, and the State Division of Forestry. Mr. Telford came to California to conduct this demonstration. Two days were devoted to classroom instruction in sawing and seasoning lumber and a one-day inspection trip was made through several sawmills near Nevada City. This meeting was held primarily for technicians of the State Division of Forestry who are working directly with many of the sawmill operators throughout the region.

Similar demonstrations conducted for sawmill operators in other regions have proved effective in improving the production and the quality of lumber sawed, and future demonstrations in California will probably also be conducted for the practical operator.

New Saw Design Tested in Mills

Sawing lumber, like many other operations involved in converting trees into finished products, is more of an art than a science. Current technology resulted largely from trial and error improvements, rather than from studies of sawing fundamentals. One fundamental study of the cutting action of saw teeth at the Forest Products Laboratory has led to the development of a new saw-tooth design, called the duo-kerf, for use on rip saws. In experimental work the new saw cut a narrower kerf than a conventional saw of the same gage steel, made a smoother cut, and required less power. The saw design is currently under test at commercial sawmills and lumber remanufacturing plants. During the summer of 1951 exploratory field tests were made at two lumber and box plants in the California pine region. The new tooth design was tried on two 18-gage band saws used to resaw lumber. The Station expects to assist in further tests on thicker hand saws and circular saws during 1952.

Kiln Operators, Engineers Seek To Improve Seasoning

Getting better lumber seasoning is an effective way of improving manufacturing practices. Good seasoning prevents loss of lumber quality, and though the savings possible through improved seasoning practices are difficult to determine, an exceedingly conservative estimate would be half a million dollars

annually in California.

One of the most encouraging signs of progress in lumber seasoning is the organization of self-help groups of kiln operators, who meet regularly to discuss drying problems. The Station has assisted these groups in organizing and in arranging programs for their meetings. Men who attended a kiln-drying demonstration in San Francisco, arranged by the Station in the summer of 1947, have formed the backbone of the Central California Dry Kiln Club. During 1951 this group met 7 times with an average attendance of 33 men at each meeting. The men who participated in the January 1949 dry-kiln demonstration in Los Angeles established an active group named the Southern California Lumber Seasoning Association during the past year. This is the seventh western club of industrial workers organized to improve lumber seasoning practices.

One significant development in this field is the so-called direct fired dry kilns. These kilns burn gas or oil and are heated by admitting the hot gases from the furnace directly into the drying chamber. The better installations of this type are capable of maintaining any commercial lumber drying schedule by means of automatic recorder-controller equipment. Water sprays, located within the kiln, provide the high humidity needed for final conditioning of the lumber to relieve drying stresses. Humidity during the drying cycle is maintained by automatic operation of vents. This kind of kiln fills a very real need for lumber drying at small plants where steam is not available, and the leading manufacturers of conventional steam-heated kilns are now studying several types of direct-fired kilns.

To help develop a research program that will be the most useful to industry, a survey of current seasoning practices in California was made by technicians from the Station and the Forest Products Laboratory. Their general observations were: (1) The use of lumber carriers and fork lift trucks has brought about great changes in lumber handling and piling practices, both on air-drying yards and in lumber dry kilns. (2) A relatively good job of kiln drying at lower cost is being done in the large kilns at sawmills, as compared with the drying being done at smaller remanufacturing plants and lumber-using plants. (3) A wide variety of dry-kilns is being built and used, including a number that appear to be considerably below the standard attained in well-designed internal-fan kilns. (4) While many direct-fired kilns do not measure up to this standard, some showed that

this type of kiln does lend itself to good kiln design and operation.

Wood Properties Studied In Young-growth Pine

The increased cut of young-growth ponderosa pine since the war has introduced a number of problems in manufacturing and seasoning wood of this species. The young-growth timber has wide growth rings, with wide bands of dense summer wood, while the old-growth timber has narrow growth rings and a more even or uniform texture. Knowledge of wood properties is needed to solve the industry's problems with young growth.

The Forest Products Laboratory is planning studies on young-growth ponderosa pine from California, but the start of this work has been deferred until studies on young-growth pine from central Oregon can be completed. The test material from Oregon was selected from different sites within a limited area to determine the relation between wood properties and timber site in the same locality. If such a relationship is found, only limited regional sampling may be necessary here. Such sampling would permit more rapid accumulation of results at a lower cost. During 1951 the Laboratory made a preliminary survey of young-growth pine in California to guide the proposed study of wood from this region.

Research Started on Douglas-fir Properties

More information is also needed on the mechanical properties of Douglas-fir grown in California. Strength values for this species are now classified under three different geographical sources of timber: Coast type, intermediate type, and Rocky Mountain type. Douglas-fir grown west of the Cascades, the coast type, is given a higher strength rating than similar material from east of the Cascades and from the Rocky Mountains. The position of California-grown Douglas-fir in this classification is not clear. Strength data on the California timber is based on test material from only two locations, one near the coast in Humboldt County and one near Lake Almanor in Plumas County. Studies of the properties of Douglas-fir from four other locations in northern California were started during the past year. The results will provide much more specific information about the structural properties of California-grown Douglas-fir. Because of the greatly increased cut of this species in recent years and the opening up of the large body of Douglas-fir timber in the North Coast Range, this work comes at an opportune time.

Better utilization of Douglas-fir may also result from research work now in progress on the properties of Douglas-fir infected with Fomes pini, the white-pocket rot. The Fomes pini organism attacks only the wood of living trees, and lumber sawed from infected timber is suitable for many uses where maximum strength is not required.

The Forest Products Laboratory is studying the properties of Douglas-fir infected in varying degree. These studies include strength properties, means of grading infected lumber, nail-holding power, seasoning characteristics, suitability for pulp and paper and for veneer and plywood. The results of these studies are already helping find uses for the infected timber, which once was not removed from the forests. Continued research toward greater utilization of infected Douglas-fir is important to California, where a large volume of infected timber will be left in the woods unless economic uses can be developed.

Veneer Tests Made On Redwood Logs

Other manufacturing problems are arising because of the rapid growth of the veneer and plywood industry in California. Both new companies and older companies from Oregon and Washington have moved in to tap California reservoir of peeler timber. The expansion began after World War II, when there were only two veneer and plywood plants in the state, both in the pine region. By 1950 the number had grown to 15, and by the end of 1951 to 29.

One important development in California is the use of woods not previously manufactured into plywood. Redwood is the outstanding example. One company is already manufacturing redwood plywood and others are interested. So far, though, little systematic experimental work has been done to guide manufacturers. In 1951 the Station arranged for shipment of redwood logs to the Forest Products Laboratory for experimental work. The preliminary studies indicate that redwood can be expected to behave quite differently from Douglas-fir and ponderosa pine, and that special manufacturing procedures will have to be worked out. Final results of the experimental work are not yet available.

New Uses Found for Sawdust and Shavings

Even with the best conversion methods, a great volume of wood is not used in manufacturing logs into lumber and other products. Finding uses for this material will help the whole industry. Much wood now

must be disposed of at an economic loss, and most plants have a surplus of wood waste above the amount used as fuel. Chipped wood from edgings and slabs is used to some extent for pulp and paper. Some block ends are also used, but sawdust and shavings are not readily used in this way. Two outlets have been suggested: as a soil conditioner and for charcoal and wood briquets.

During 1951 the number of requests for information on the use of sawdust, shavings, and similar material as a soil conditioner increased greatly over the number received by the Station in previous years. Fortunately several new publications on the subject were available for distribution. Requests for information came from lumber producers who had wood waste available and from potential users. The Station was able to bring some of these groups together, and a significant volume of shavings and sawdust is now being used.

The demand for information has real significance for improved utilization of forest products. It reflects growing acceptance of mill left-overs for agriculture, and growing experimental evidence of benefits from using the material as a soil conditioner. During the year the Station arranged a conference with the California Redwood Association and the Soils Division of University of California to discuss experiments in the use of redwood sawdust as a soil amendment. Following this meeting, the Association set up a small but well-planned experiment on the use of sawdust on heavy soil near the south end of San Francisco Bay. Already additional work is planned on an expanded scale.

Converting some forms of wood that are not readily utilized into charcoal or pressed-wood briquets appears to have promise. Thus far only hardwood is used extensively for charcoal, but softwood left-overs can also be used. Judging from talks with local charcoal producers and processors prospects look fairly good for converting chunk type left-overs into charcoal, particularly if the charcoal is further processed into pellets or briquets that are less bulky to handle and transport. Inexpensive equipment for pelletizing sawdust and shavings should also find wide application in converting this material into fuel.

California Hardwoods Offer Promise for Development

Another potential source of raw materials for forest industries is the hardwood timber of the region. Most of the conifers of California are already used extensively by the lumber industry.

most used of all western hardwoods and offer no special technical difficulties in manufacture. They should become more widely used wherever they grow in sufficient volume.

California black oak could also be manufactured more extensively. Experimental seasoning of California black oak, reported by the Station in 1949 and 1950, has shown that this species can be dried with little difficulty. Drying schedules were recommended in these reports, and the studies were followed up by additional work in 1951. The latest results affirm the recommendations outlined earlier. Manufacturers of hardwood flooring in the Midwest and South are showing interest in this oak. The Station is arranging studies to learn how California black oak compares with eastern and southern red oak when manufactured into lumber, seasoned, and remanufactured into flooring at a typical commercial flooring plant.

The Forest Products Laboratory is also studying physical properties of California black oak to determine its application in other fields. California black oak, though one of the red-oak group, is similar to the white oaks in being impervious to liquids, so that it may be possible to use this local oak for tight cooperage. Experimental material was also sent to the Laboratory for testing the preservative treating of California black oak. Favorable results may open up other uses, such as in ship building.

GROWING AND USING THE FORAGE CROP

Perhaps twice as much wild land in California is suitable for production of forage crops as is suitable for commercial timber production. The range resource has not been inventoried as the timber resource has, but most estimates agree that about one-third of the State's 100 million acres can be used for grazing. This includes many kinds of range land: low-elevation grasslands next to agricultural areas, woodland-grass a little higher up in the foothills, dense woodland and brush still higher, sagebrush on the northeastern plateau, and finally, in the forested mountains, grassy meadows and open forests with an understory of forage plants.

Circular Gives Results of Foothill Forage Studies

Foothill range lands are the backbone of the State's livestock industry. They are the most extensive block of grazing land, encompassing some 30 million acres--about 10 million in open grasslands,

the rest in brush and woodland, some of which can doubtless be developed into valuable ranges. They are strategically located--close to irrigated pastures, sources of supplemental feeds, and markets. They grow a forage crop composed mostly of annual plants.

How to use this crop efficiently has been worked out in the first phase of range research at the Station's field branch, the San Joaquin Experimental Range, near O'Neals, and the results were published during 1951 in U. S. Department of Agriculture Circular No. 870, by J. R. Bentley and M. W. Talbot. In this 14-year study, green forage on the foothills was adequate for maximum livestock growth an average of 127 days a year, in the late winter and spring months. Supplemental feeding practices developed in correlated studies by the University of California make possible efficient use of the forage during the remainder of the year. The Station's work on forage growth and the effects of different degrees of grazing showed the desirability of moderate grazing to maintain good range condition and demonstrated how to lengthen the period of adequate green forage. Grazing capacities were also determined for several different sites on the experimental range. By following suggestions in Circular 870, California cattlemen can go a long way toward meeting the need for year-round forage.

Range Fertilization Pays in Foothill Tests

The Station is now seeking ways to improve the natural annual-plant forage. Since range fertilization appears to be one of the most promising ways, tests of commercial fertilizers were stressed at the San Joaquin Experimental Range during 1951. The aim is to increase forage yields and improve forage quality, thereby increasing livestock production and reducing the need for supplemental feeds. Earlier, exploratory studies showed increased grass production on all sites in this locality from application of nitrogenous fertilizers. Also, sulfur-bearing fertilizers increased legume production, which in turn stimulated grass growth in following years. Thus, both forage yield and quality were improved by sulfur. Inclusion of phosphorus with sulfur increased legume production in most swales but not on slopes. The response from sulfur fertilizers persisted over a period of three or more years.

One series of tests now in progress is comparing the relative effects and economy of different sulfur-bearing fertilizers, including soil-sulfur, gypsum, gypsum-sulfur mixture, superphosphate, and superphosphate-sulfur mixture.

Each of these has produced economical returns when the forage yield was evaluated as hay. For example, each fertilizer was applied at a rate equivalent to 60 pounds of sulfur per acre. Considering the prevailing cost of the fertilizer, the cost of extra hay produced during the years 1949-51 from a single fertilization was:

Fertilizer	Cost of extra hay, per ton
Gypsum	$ 2.77
Gypsum and sulfur	4.15
Superphosphate and sulfur	6.05
Soil sulfur	7.00
Superphosphate	8.50

Further small-scale tests are needed to determine the best rates and times of application; at present, though, gypsum seems most economical for pasture-scale use.

A 40-acre range area was fertilized in January 1949 with a mixture of superphosphate and sulfur and a similar unfertilized area set up as a control, to measure benefits from fertilizers in terms of weight gains by weaner steers. This test is being conducted in cooperation with the Division of Animal Husbandry, University of California. In 1951, the fertilized range yielded 4,272 pounds of herbage per grazable acre compared to 2,495 pounds in the unfertilized area. The increase included 391 pounds of legumes and 1,466 pounds of grass per acre; yield of filaree and certain other species was reduced. Further hold-over response is expected during 1952. As steers have used this range only since 1950, effects of the forage growth on cattle production cannot be evaluated as yet. But some differences in grazing habits have been observed. In 1950 the steers on fertilized forage grazed as a group and concentrated on areas where the growth of clovers had been most lush, while the steers in the control area were more widely scattered and less selective in their diet. This difference was not noticed in 1951. In both years, however, the steers in the fertilized area were easier to approach and traveled less during their grazing periods.

As a practical demonstration of current range-improvement knowledge, a large-scale test has been started on 1,200 acres of the Experimental Range. The results will be measured by beef production from the University of California breeding-cow herd that is confined to this area. To start

with, two methods of fertilization are being used. One 280-acre area of fairly open range was fertilized with crude bulk gypsum in October 1951, using a large commercial spreader. Soil sulfur is being spread on another area by airplane. Range rodents which eat forage species are to be controlled. Undesirable brush that competes with forage species for growing space will be controlled, and some spots with little or no forage will be reseeded.

Brushland Studies Seek More Forage

Just how much of the brush and woodland types can be made to grow good forage crops is not known. Land in these types varies widely in ease of clearing, in fertility, and in susceptibility to damage from runoff and erosion when the land is cleared. But any part of the brushlands that can be permanently converted to good grass cover will make a much-needed contribution to livestock production in the State, which already consumes more meat than it grows. Some answers on the best land to choose for conversion are coming from the soil and vegetation inventory mentioned earlier in this report. Further answers, on both selecting conversion sites and making the conversion, are accumulating rapidly from brushland improvement studies conducted by the Station, several State agencies, and stockmen.

Techniques Improved For Brush Removal

How to add to the effectiveness and safety of burning as one way to remove brush is the aim of one interagency study in which the Station is participating. One of the first contributions was a series of five articles on planning and conducting controlled burns ("Use of Fire in Land Clearing," by R. Keith Arnold, University of California; L. T. Burcham, State Division of Forestry; Ralph L. Fenner, California Forest and Range Experiment Station; and R. F. Grah, Agricultural Extension Service). Then experiments were started to learn how cleaner burns, with less danger of escape, could be obtained.

The most important result from the past year's work was the development of a technique that produces effective burns during relatively cool and humid weather. Under these conditions, standing brush cannot be cleared by conventional broadcast-burning methods. In the burning technique under test, strips of brush are smashed down and allowed to dry. Fire is started throughout the length of all these strips as nearly as possible at the same time. This technique, called area ignition, will allow spreading of controlled burning over a longer period of the year, will permit burning of

small areas to reduce wildfire hazard or for other reasons, and can be used to prepare wide firebreaks around areas to be burned by conventional methods. Future field work will seek mainly to determine the limits of fuel and atmospheric conditions under which this method can be most effectively used.

Possibilities of clearing brush with heavy tractor-drawn disk plows have been explored in trials conducted by the Mendocino and Los Padres National Forests. Disking was most effective on chamise brush. Measurements of sprouting plants and new seedlings show that few chamise plants survived the first year after either single or double disking. Disking scrub oak and manzanita has opened the brush cover only temporarily. A full stand of sprouting plants is left. Deer can keep oak under control for a few years, but the unpalatable manzanita rapidly develops a full cover. Other methods of clearing, combining fire and chemicals, may prove to be more effective for controlling oak, manzanita, and similar sprouting brush.

Grass Stands Established In Woodland-Chaparral Tests

Once the brush is cleared reseeding is usually necessary to provide a forage crop, protect the soil from erosion, and retard regrowth of brush. Judging from the Station's results, which are in agreement with those of other workers, native grasses in the open woodland-grass types will regrow after a burn on all but the "hot spots" where brush thickets have been consumed. These spots and other types of brush cover require artificial reseeding.

The most favorable sites for reseeding have been in dense woodland-chaparral, a mixture of scrubby trees and shrubs, growing on at least moderately fertile soil. Here, burns have left a good seedbed, and broadcast sowing has given consistent success with a variety of grasses. Domestic ryegrass, sown at 5 pounds per acre, produced a fast-growing, inexpensive forage cover in one year; but annual grass alone will not raise forage yields to the levels that deep, fertile soils are capable of producing. Domestic ryegrass can be sown at a lighter rate in a mixture with perennials such as Harding grass, tall fescue, smilo, orchard grass, or tall oatgrass. Mixtures like this have provided a fairly full cover the first year; they should be adapted to a wide range of growing conditions but may not result in maximum forage production from the best soils. Sowing only adapted perennial grasses shows promise for obtaining full production

from areas of deep, fertile soil, though the species best adapted to each site have not yet been determined. One of the major remaining problems is how to increase legumes in the cover. Reseeding such legumes as rose clover, burclover, or common alfalfa is recommended because best forage production should come from stands containing these plants.

Few Conversions to Grass Succeed in Chamise Tests

Attempts to convert brushlands covered by chamise, on the other hand, have mostly been unsatisfactory. In tests on Los Padres and Mendocino National Forests, results were less successful and more variable than were results in the woodland-chaparral. Broadcast sowing has not proved to be a consistent, positive method for reseeding burns in chamise types, particularly on southerly exposures, steep slopes, and very shallow soils. Even on the better sites the hard surface typical of burned chamise land was an unfavorable seedbed for broadcast sowing. Drilling into disked seedbeds, however, produced good first-year stands of grass in some tests. Broadcasting on disked areas gave spotty stands. Grass species that have been most successful include ryegrass, smilo, Harding grass, and tall oatgrass. Legumes have been unsuccessful in most of the tests in burned chamise. Volunteer growth of annual forage species established a full vegetative cover on some disked areas in open stands of chamise.

All in all, preliminary results have not been sufficiently uniform or encouraging to warrant specific recommendations for chamise types in general. Extensive acreages in large burns in chamise types have had little natural reestablishment of herbaceous species in two years. The erosion hazard is certainly increased from laying bare entire drainage basins or very steep slopes for such a period. Results to date suggest that much more needs to be learned about how the conversion job should be done and about the site limits beyond which conversion of chamise types is either impossible or impracticable.

Most tests are just reaching the stage when the effects of reseeding on the control of brush reinvasion can be determined, but preliminary findings again show differences between woodland-chaparral and chamise types. In burned woodland-chaparral, reseeding of annual ryegrass has produced a dense cover that crowded out many brush seedlings the first year. Reseeding of perennials has been much less effective. On two test areas sown in 1949 with annuals and perennials, most remaining brush seedlings were apparently

killed by a reburn in 1951. Reburning areas with such heavily sprouting species as liveoak and toyon, however, has not killed the plants. Results of cooperative tests with the farm advisor in Tuolumne County promise effective and practical control of such sprouts on good sites by hand spraying with chemicals.

In burned chamise, the first-year reseeded stands were inadequate to kill brush seedlings through competition, except on ryegrass plots in one test on a good site. Disappointingly poor results were obtained from an attempted reburn to kill chamise sprouts and seedlings during the second season after sowing. In only a few places was sufficient grass grown to carry a fire.

Sagebrush Controlled by Disking and Spraying

Sagebrush areas in northeastern California present much the same kind of problems as brushlands in the foothills: How can undesirable vegetation be removed? What forage species should be planted, and how? What land is most productive of forage crops? Of course the climate and terrain are different, and the natural forage is mostly perennial bunchgrass instead of annual plants. Consequently, what is learned in the Station's studies of how to increase the productivity of depleted sagebrush ranges is directly applicable only in the 5 million acres of Great Basin sagebrush. But techniques and principles developed here should also be useful in the 2 million acres of Coastal sagebrush as well as in the foothill brushlands.

Of four kinds of tillage equipment tested for use in controlling unpalatable weeds and brush, the disk plow has proved best for controlling sagebrush. The disk plow gave 99 percent reduction in crown area of the three common species of sagebrush. Results with other equipment were: offset disk, 90 percent control; wheatland plow, 80 percent; and tractor mower, 60 percent. But some range land is too rocky and rough for disk plows. This land can be readily sprayed with chemicals. Sagebrush has been found susceptible to 2,4-D spray in the spring when new twig growth is 3 to 4 inches long, usually late May or early June. Butyl ester formulation has been superior to the isopropyl ester or sodium salt form of 2,4-D. Application has been made by ground sprayer, airplane, and helicopter.

Best results with present equipment have come from using at least 10 gallons of spray solution per acre. For ground sprayer and airplane, 1 pound of 2,4-D in the solution

gave 95 percent control of sagebrush. Helicopter spraying gave 92 percent control with 2 pounds per acre, but only 76 percent with 1 pound. The chemical does not seem to be translocated very far through the woody portion of the plant. Therefore, kill of the sagebrush depends upon how well the spray solution covers the foliage. Application by ground rig gave excellent coverage, airplane gave fairly uniform coverage, and helicopter somewhat less uniformity of distribution over the width of swath sprayed. A new test of airplane spraying on sagebrush range was started in 1951 to determine whether less gallonage can be used by increasing the concentration of the solution. Results of these tests will not be known until the summer of 1952.

Killing the sagebrush has resulted in marked increase of forage production from native grasses. In one test, for example, a depleted sagebrush range produced only 285 pounds of grass per acre. Sprayed with 2,4-D, the sagebrush died out, and the thin cover of perennial grass, once struggling for existence, grew rapidly. In the first year after spraying, this area produced 642 pounds of grass per acre. Killing unpalatable plants has also favored grass in meadow types; one meadow infested with buttercup and other weedy species grew only 242 pounds of grass per acre when untreated, but a part of this meadow grew 1,028 pounds when sprayed with 2,4-D. Even greater forage increases have been realized when undesirable plants were controlled and the range reseeded with adapted forage species.

Grass Species Compared For Use in Reseeding

In testing adaptability of grasses for range reseeding, many species and strains of forage plants from native and foreign sources have been grown in nursery rows. Relatively few, however, have performed well in field-scale seedings in northeastern California. Of those that have done well, the outstanding species has been intermediate wheatgrass, which consistently produced good forage yields. Nine grasses included in a 3-year seeding test on depleted sagebrush range have been ranked in the following order of descending yield: intermediate wheatgrass, tall wheatgrass, slender wheatgrass, western wheatgrass, beardless wildrye, pubescent wheatgrass, crested wheatgrass, smooth bromegrass, and timothy. The highest producing strain of intermediate wheatgrass carries the Soil Conservation Service accession number P-2327. Big bluegrass, beardless wildrye, and many of the legumes and browse species have shown desirable qualities in the nursery, but seeding procedures to insure establishment under field

conditions have not been developed.

"Good Farming" Aids Range Reseeding

Experiments in how to prepare suitable seedbeds and plant seed of forage plants are showing that "good farming" pays off in range reseeding. A test begun in 1949 on a plowed sagebrush area, first indicated that a land roller should be used. Using the roller after plowing and ahead of drilling seed has resulted in more seedlings and higher forage production. Disking the plowed land ahead of the roller gave some advantage by leveling the soil surface and reducing size of air pockets. However, disking alone ahead of drilling was not as satisfactory as rolling ahead of drilling.

Press wheels did not prove better than the ordinary chain drags now widely used with disk drills to cover the seed and firm the soil after drilling. No great difference was found between three types of furrow openers tested in this experiment. Single disk openers, the type most commonly used, gave slightly higher seedling establishment than the deep-furrow type. Double disk openers with depth control bands gave fewer seedlings per unit area than the deep furrow openers.

Plantings on 7 national forests are beginning to show the productive capacity of different range sites. On the Lassen National Forest, for example, plots have been seeded on range sites dominated by three different species of sagebrush. Without reseeding a silver sagebrush area averaged 59 pounds of grass per acre during 1950 and 1951; a black sagebrush area produced 182 pounds; and a big sagebrush area, 254. On plots plowed and seeded, comparable yields of grass per acre for the same period averaged 1,063, 1,054, and 972 pounds, respectively. A depleted, dry meadow area produced 166 pounds per acre without treatment; 1,142 pounds when plowed and seeded.

One area selected for reseeding was so badly depleted of vegetative cover and so eroded that perennial forage plants had largely been replaced by tarweed. Without seeding, no available grass was produced. This meadow produced 41 pounds of grass per acre when plowed and seeded, and 577 pounds where fertilized and seeded.

Soil tests have shown most depleted sagebrush range in northeastern California to be deficient in phosphorus, calcium, and sulfur in local areas. A rather widespread

deficiency of nitrogen for maximum grass production is recognized, and nitrogenous fertilizer applied to well-established stands of grass has increased forage production rather consistently on several different mountain ranges.

New System Proposed For Mountain Grazing

In 1951 the Experiment Station started a large-scale test of a grazing management system that shows greatest promise as a means of maintaining full forage production from summer ranges in the high plateau region of northeastern California. The mountain ranges in this locality are estimated to be producing only about half of capacity. Restoration of these lands to full production is urgent because more summer forage is badly needed. The grazing system has developed from studies conducted at the Burgess Spring Experimental Range, Lassen National Forest, from 1936 to 1949.

These studies were carried out with cattle in fenced units in cut-over pine timber and open grassland. Close study was made of the vegetation, the grazing habits of cattle, and the reaction of both the vegetation and cattle to grazing. It was found that restoration and maintenance of the ranges was vitally dependent on periodic resting of the range from grazing in addition to proper stocking, proper season of grazing, and good livestock distribution. This rest in bunchgrass-type ranges is needed to restore the vigor of grazed plants and promote reproduction of the good perennial forage plants. Under continuous seasonal grazing, now practiced almost universally on high mountain summer ranges in the State, it was found (1) that the choice forage species on the choice grazing sites were invariably closely and destructively cropped because of the selective grazing habits of the cattle; and (2) that this was a vital wound, leading to progressive deterioration of the range.

To prevent deterioration, a system of grazing management providing the needed rest was designed. Based on the growth requirements of the vegetation and the grazing habits of cattle, the system calls for subdivision of the range into a minimum of five pasture units to permit application of grazing at the time and to the degree needed. Bases for proper seasonal grazing and proper stocking were also developed. This information has application on bunchgrass ranges in the Great Basin Region of California and in other areas in the West. The first draft of a manuscript covering these findings is about completed. It is designed for publication as a U. S. Department of Agriculture circular.

Pilot Test Started On Range Allotment

Plans have been formulated to make a pilot-plant test of the proposed grazing system, together with promising cultural practices like artificial reseeding and weed control. This test is aimed at revealing the effectiveness of these combined measures in restoring the productive capacity of the range, increasing grazing capacity, and promoting more efficient range use. Scene of the test is the Harvey Valley range allotment on the Lassen National Forest. National Forest Administration will install the necessary range management facilities and, with the cooperation of the grazing permittee, apply the grazing system and cultural treatments. The Experiment Station will measure the reactions of the range and livestock to grazing and to the cultural practices.

During the past year the first of the five fenced range units was constructed. Within this subdivision approximately 1,750 acres of sagebrush were sprayed with 2,4-D. In addition, 300 acres were reseeded with smooth bromegrass and crested wheatgrass. This subdivision will be rested season-long during 1952 to enable the reseeding stands, and seedlings of native species, to become established according to the plan. The remainder of the development and cultural work on the allotment will be put in as rapidly as money becomes available for the work. The necessary experimental work will include measurements of vegetative and soil changes, range utilization, and weight gains of cattle. Costs and returns will be recorded to throw light on the economic feasibility of such a program on private as well as public lands.

IMPROVING WATER YIELD

Several years of drought no less than the recent winter floods have served as reminders that California's timber and range lands must also be managed for yields of water. In fact, the California Blue Book for 1950 calls water "the State's most important and valuable natural resource." Certainly an ample supply of irrigation water is essential to agricultural crops, the State's primary source of wealth. Cities and industries need water for their growth, too, and all three--farms, homes, and factories--must be protected from damage by floods. The Station's concern with these needs is to learn how the wild-land watersheds can be managed to insure maximum yields of clear, usable water with a minimum of flood runoff and soil erosion.

New Bulletin Describes Water Yield Processes

The basis for this kind of management is knowledge of how a watershed functions: both the "what happens" and the "how much" of water and soil movement under many different watershed conditions. During 1951 the results of studies showing what happens to the rain and snow of two California areas were published in U.S.D.A. Technical Bulletin 1048, by P. B. Rowe and E. A. Colman. This bulletin describes experiments conducted in woodland-chaparral and young ponderosa pine stands in the Sierra Nevada of central California and in chaparral-covered watersheds in the San Gabriel Mountains of southern California. Controlled water yield is an important objective of land management in both these localities. In brief, the study showed that (1) of the total annual rainfall from 5 percent in woodland chaparral to 12 percent in ponderosa pine was intercepted by vegetation and never reached the ground. (2) The quantity of water entering the soil varied directly with annual rainfall. (3) The amount of water evaporated from the soil and used by plants was quite uniform each year, ranging from 14 inches in woodland chaparral to 19 inches in chamise. (4) The amount of water percolating through the soil varied from place to place in response to soil differences and from year to year in response to differences in the amount and distribution of rainfall.

When some of the experimental plots were burned each year, burning reduced interception loss and thus increased the amount of rain reaching the soil. But burning also reduced the capacity of the soil to absorb water and greatly increased surface runoff. Evapo-transpiration losses were not appreciably changed by burning. The net result was that total water yield from burned plots was slightly greater than from unburned plots, but the increase was achieved at the expense of greatly increased storm flows of surface runoff, often heavily charged with sediment.

This study suggested that true water yield in the experimental areas can be determined more accurately by subtracting water losses from total rainfall than by measuring stream flow. Water-loss accounting was applied to records for Monroe Canyon, a chaparral-covered watershed in the San Dimas Experimental Forest, near Glendora. Of about 31 inches of rainfall, some 2.5 inches was caught by vegetation, so that 28.5 inches entered the soil. Water evaporated from the soil and used by vegetation accounted for less than 11 inches, leaving about 18 inches to percolate through the soil. Only 4 inches of this left the watershed

as measured stream flow. The remaining 14 inches, it was concluded, left the watershed as underground flow through cracks and other passageways in the rock beneath the soil.

Plants Compared For Water Use

Some differences in the water used by several plant species were apparent from lysimeter records summarized at the San Dimas Experimental Forest. The lysimeters are tanks or large blocks of soil equipped to determine the influence of vegetation on surface runoff and water loss from the soil. Four native shrubs, buckwheat, chamise, ceanothus, and scrub oak, and Coulter pine have been studied since 1946. Two lysimeters were planted with native bunchgrass in 1951.

During the period 1947-1951, runoff varied among the species and as the cover matured, differences in runoff being associated with differences in litter production. Buckwheat began producing a litter layer during the first year; this favored infiltration of water into the soil and low runoff. Lysimeters planted to pine, which did not start dropping needles until 1951, had the highest runoff. Oak shrubs began producing litter in 1948, and runoff began to decrease. All five species dried the soil to or below the wilting point every summer, but the soils in the buckwheat, chamise, and ceanothus were somewhat drier than those in the oak and pine lysimeters. This study also showed that the species could endure summer drought periods of 4 to 6 months when the soil was close to or below the wilting point. Only the Coulter pine remained green. Buckwheat and chamise plants dropped almost all their leaves. Ceanothus leaves that stayed on the shrubs turned grey or yellowish. Almost all leaves and many small branches of the scrub oak turned brown and died. Despite these signs of stress, the plants began growing again when water became available.

Erosion Process Studied In Southern California

Erosion in headwaters areas of the Los Angeles River watershed was investigated in cooperation with the Los Angeles Flood Control Project of the Forest Service. J. L. Retzer, soil scientist from the Rocky Mountain Forest and Range Experiment Station, was in charge. He was assisted by Irving Sherman, of the Arcadia Soils Laboratory, and four foresters from the national forests of southern California. They examined 4,008 acres in 46 small watersheds ranging in size from 20 to 234 acres.

Objectives of the investigation were to study the processes of soil and rock movement on steep slopes, the

conditions under which various kinds of movement occur, and the means of recognizing the different kinds of movement. The study was concerned primarily with the origin of sediments and not with their movements after they had entered the larger stream channels. The study was qualitative; no quantitative analysis was made of the amounts of material moved or moving, nor of their rates of travel.

The inventory of physical conditions in this rugged country revealed that: (1) the surface area is 20 percent greater than the map area; (2) average slope of the land is 68 percent; (3) the angle of repose is approximately 70 percent; (4) 59 percent of the land is steeper than the angle of repose; (5) the area contains 180 linear miles of drainageways averaging 3.9 miles per watershed; (6) on the average, 2.0 miles of channel are eroding and 1.9 miles are stable; and (7) channel gradients average 44 percent, or 2,300 feet per mile, with a range from 612 to 3,660 feet per mile.

The sources of eroded sediment in their approximate order of importance were found to be: (1) stream banks and slopes rejuvenated by undercutting, (2) slopes with south exposures, (3) very steep upland slopes, (4) fault zones and steep fault faces, and (5) deep colluvial-alluvial deposits on upland slopes when undercut by roads or streams.

The active agents of erosion were found to be gravity, water, wind, and the daily freeze-thaw cycle, the latter mainly at high elevations.

Sediment was found to move from the land in two ways; namely, as grain and granular movements on the soil surface, and as deep-seated movements of soil masses. Granular sediments moved as dry creep and as slope wash. Both creep and wash were found very active all over the area, especially on south-facing slopes where the plant cover was poor. Slides constituted the most common form of mass land movement. They result from the force of gravity acting on overly steep slopes. Gravity is aided by undercutting, by the tendency toward slippage of the overburden on tilted rock surfaces, and by the weakened rock structure in fault zones. The most important disturbance causing slides in this area was undercutting.

The study showed that a dense brush cover does a good job of soil stabilization, even on slopes steeper than the angle of repose. There are slopes so steep, however, that

severe soil loss occurs in spite of the vegetation. Such sites must be controlled with the aid of engineering structures.

Better Cover Sought For Eroding Slopes

The Station has started experiments aimed at improving the watershed cover on slopes growing only sparse stands of vegetation. This work is also being done as part of the Los Angeles River Flood Control project, in cooperation with the Angeles National Forest and the California Institute of Technology. Two possible ways of improving the cover are being tested: (1) Increasing the density of native vegetation, and (2) introducing plants from other localities.

One of the first things tried was a greenhouse study to determine whether or not native plants would respond to improved nutrient levels in the soil. Several plant species were grown in soil derived from the three major rock types (Lowe Granodiorite, Wilson Diorite, and Anorthosite) of the Los Angeles River watershed. Five nutrients were added to the soil, namely, nitrogen, phosphorus, potassium, sulphur, and a mixture of five micro-elements including boron, copper, molybdenum, zinc, and magnesium. Tests with native canyon live oak, Coulter pine, and big-cone-spruce on these soils have shown that nitrogen was deficient in all cases. In many instances a phosphorus deficiency was also indicated. (The micro-element mixture, in the concentration applied, was toxic.) Addition of potassium and sulfur produced no response in the plants, showing that the soils have adequate amounts of these nutrients. This study showed what elements should be tried in the field.

Field tests conducted with nitrogen and phosphorus in the spring of 1951 confirmed the greenhouse findings on nitrogen. New growth on shrubs in a nitrogen-treated plot was almost double that on shrubs in an untreated plot. There was no significant increase in the growth of shrubs with added phosphorus. These tests were carried on during one of the driest years on record. The results showed that deficiency of nitrogen is a limiting factor for growth of chaparral species, even during the short growing season of drought years.

The next question is how can nitrogen in the soil be increased at minimum cost in these rugged mountains? A common method used in agriculture is to plant a legume that is capable of fixing nitrogen from the air. This possibility

will be tried on the watersheds by testing several native plants for their ability to increase nitrogen in deficient soils.

Of course, some plants hitherto unused may have value for soil stabilization in southern California. Therefore a project of locating and testing untried native and foreign species was started in 1951. A botanist was employed for 6 months to search the literature on plants known to grow naturally in a climate similar to that of southern California. He also visited herbaria and botanical gardens and consulted botanical authorities. In this way he found approximately 85 species of plants which promise to meet the exacting requirements of cover-improvement work. It is planned to continue the search in 1952; meanwhile species proposed for introduction will be tested in the temperature-controlled greenhouse at California Institute of Technology before field plantings are attempted. The tests include studies on germination, growth, response to temperature, dormancy, frost resistance, and drought resistance. It is hoped to provide by this procedure a rapid method of checking new species.

To help establish specifications for plants to be used in soil stabilization, a study was made of the rooting characteristics of chaparral plants. The roots of 76 plants of 18 species were excavated hydraulically. Examinations were also made of roots exposed by road cuts. It was found that the lateral spread of the roots was nearly always greater than the crown spread of the plants. Most of the chaparral roots were found in the 3 to 8 foot layer of soil material. Some species, such as chamise and scrub oak had definite tap roots, and a few of these penetrated cracks in rocks to depths of 25 feet. Species such as black sage which were fibrous rooted, had a fine mat of roots close to the surface and few roots in the deeper soil layers.

Gully Control Reviewed In Mountain Meadows

Methods of restoring the plant cover and stabilizing the soil in watersheds damaged by past abuse are under investigation by the Station in other parts of the State. One current study is concerned with mountain meadows in the Sierra Nevada and the North Coast Range. During the 1951 field season several meadows were examined to appraise the effectiveness of past erosion-control work and to observe the trend of erosion. The hydrologic functions of many mountain meadows--in reducing floods by retarding the escape of snow-water in late spring,

and in storing water to feed springs and summer streams--may be more valuable than their forage production. In many places gullies have impaired or destroyed those functions. Gully control, with the multiple objective of retarding runoff, raising water tables, restoring forage, ultimately eradicating the gullies, and reducing or stopping the movement of eroded soil into downstream reservoirs, should have high priority. Under the system of range management based on research at Burgess Spring Experimental Range, gully control work in the mountain meadows can be undertaken with better prospects of success than formerly. The periodic "rest periods" included in that system will afford the necessary protection to newly installed gully structures and plantings. This protection has been difficult to achieve in the past because of the cost of fencing each gully.

Planting, Gully Plugs Rehabilitate Shasta Area

Erosion-control measures were also recommended for use of National Forest Administration and the Bureau of Reclamation in an area near Shasta Dam. This area was denuded by smelter fumes about 40 or 50 years ago. First, reforestation of the area to control erosion is possible and practicable without elaborate terracing or other preparation of the soil. Three measures, used in combination, were recommended as essential for success; no one of them alone can do the job. Planting conifers, chiefly pines, at a spacing of not over 6 x 6 feet throughout the area, is the most important measure and the one that will ultimately provide permanent control. Second, planting willows in gullies is recommended to restrain gully erosion, and to bolster gully plugs and small check dams. The plugs and check dams, the third measure, prevent enlargement of gullies during the 6 to 10 years required for the planted conifers and willows to establish vegetative control of erosion.

Erosion Measured on Burned Watersheds

That much soil may be washed away when watersheds are laid bare was indicated by measurements on two areas denuded by wildfire in southern California. One was the Green River burn of 1948, on the Cleveland National Forest in Orange County. During the first winter after the fire rainfall was light, and there was little water erosion but much wind erosion. The second winter after the fire, 1949-50, brought rainfall sufficient to cause runoff. Measurements of gullies showed that 49,000 cubic yards of soil per square mile had been eroded from the denuded slopes. Accumulations of sand and gravel in the streambeds ranged

from 865 cubic yards per mile in a small headwaters tributary, to 9,955 cubic yards per mile in the main canyon. The burned-over canyons discharged heavy deposits of sand and gravel; adjacent unburned canyons had clean channels and no evidence of accelerated erosion. The other burn occurred in 1950 on the Jackson Ranch, San Bernardino National Forest. Here, erosion of more than 20,000 cubic yards per square mile in a single storm occurred as a result of the fire, according to calculations completed in 1951. A field examination showed that debris flows formed in all of the burned or partly burned canyons, but there was no debris movement in adjacent unburned canyons which received the same or heavier rainfall.

Studies Begun to Weigh Effects of Range Fires

Since fire is one of the many tools used in managing timber and range resources, two questions are frequently asked about the use of fire: Will the yield of water in springs and wells be increased by burning the plant cover? Are runoff and erosion affected? Three studies recently begun should help answer these questions.

Determining the conditions under which brush-burning on watershed land is or is not followed by increased runoff and erosion is the objective of one study, a statewide survey begun in the winter of 1950-51. The study will cover areas burned in the last 25 years, insofar as records are available, to include periods of high and low rainfall. Information on the older burns will be gathered from file records and published reports. Current information has been obtained from forest rangers' reports of erosion and from first-hand observations.

Reports were received from 58 rangers listing approximately 1,000 burns of the last 25 years. Erosion was reported in about 25 percent of the burns, and no erosion in 35 percent; no information was given for the remaining 40 percent. Information on cover type and slope was reported for 346 burns. Erosion was reported in 7 percent of the woodland-grass burns, 35 percent of the burns in chamise type, and 37 percent of the burns in brush-woodland. Erosion was reported in 5 percent of the burns on gentle slopes, up to about 30 percent gradient; on 7 percent of the moderate slopes, from roughly 30 percent to 50 percent gradient; and on 52 percent of the steep slopes, with gradient above 50 percent.

First-hand observations were made by the Experiment

Station staff during the winter of 1950-51. Of 75 burned areas examined, 52 showed accelerated erosion attributable to the burning, 17 showed active erosion but no comparable slopes for determining whether or not the erosion was accelerated, and 6 showed no acceleration. Generally, less erosion was observed on burned-over grassland than on burned-over brushland.

Analysis of the current observations is being made, seeking correlations between erosion, rainfall, plant cover, soil, and steepness of slope. Information from file records on older burns remains to be incorporated with that currently gathered.

Another study is in a control burn made for range improvement on the San Joaquin Experimental Range. Cover of the area before burning was open woodland-grass with thickets of oak, Digger pine, ceanothus, and other chaparral species. Topography of the area was gentle, the slopes generally being less than 30 percent gradient. Daily measurements of 15 wells and springs in and near the burned area were made for 12 days before the fire and 12 days after the fire, and at longer intervals during the remainder of the first summer. In the summer of 1951 the same wells and springs were observed but not measured. Water yield was not changed by the burning, in either the first or the second year. Surface runoff and erosion were generally low in the burned area during the winter of 1950-51. Heavy rainfall occurred, together with warm temperatures which promoted early growth of volunteer grass and forb cover on the burned-over grassland. There was little or no erosion where grass cover had been burned, but moderate erosion on bare slopes where patches of brush had been burned. Overall, little soil was lost because of the low runoff, the good cover of early-growing grasses and forbs, and the presence of unburned grass roots which did much to stabilize the soil. Continued observations in the area are planned until the burn is 5 years old.

The third study is in experimental watersheds of the Station's Kings River field branch. This branch station, inactive since World War II, was made ready for limited operation during the winter of 1951-52, in order to record the effects of a wildfire that burned over the low-elevation Big Creek watersheds July 7-9, 1951. Fire consumed the dry grass, but did not destroy many trees. The burn was moderate and locally heavy on the upper slopes, but light on the lower slopes where most of the grass had been removed by heavy grazing. These watersheds vary in size from 9 to 36

acres. Records of precipitation, runoff, and erosion taken from 1936-37 through 1945-46 provide a good basis for comparison with measurements after the fire.

IMPROVING WATERSHEDS FOR FLOOD CONTROL

The term flood control has long been synonymous with large dams, river-bank levees, and similar downstream protective works. As a function of land management, flood control has been less readily understood. It was only 15 years ago, for example, that Congress created facilities for coordinated land and water progrems. This was done in the Omnibus Flood Control Act of June 1936, which declared that flood control requires not only the improvement of rivers and other waterways but also the treatment of the lands that shed floodwaters. Congress specified in the Act that responsibility for the improvement of rivers and waterways would rest with the Department of the Army and that investigations and measures for improvement of watersheds would be under the jurisdiction of the Department of Agriculture. The Forest Service and the Soil Conservation Service act as the Department's agents. This Station currently has responsibilities for flood-control surveys in all three Pacific Coast states.

Preliminary Studies Made For Most of California

The first step in this work is to determine whether watershed treatment programs appear to be justified and whether surveys should be made. This preliminary examination has been made for all but a few of the California watersheds for which Congress has authorized a flood-control survey. The latest preliminary report was prepared in 1950 for the Klamath River watershed in northern California. This report, approved by the Secretary, recommended a survey be made. Among the watersheds not yet examined are the Mojave, Whitewater, and Salton Sea drainages.

Special investigations are also made well in advance of the flood-control survey work to provide basic data that will be needed in designing or evaluating flood-control measures. Budget reductions in the past few years have restricted the advance study plans so severely that this line of work is now largely confined to incidental collection of reference material for future surveys.

One advance study was started in 1949 to measure

erosion from skid trails in logging areas. Four small sediment basins installed for this purpose on the Stanislaus Experimental Forest were remeasured for the third time in the fall of 1951. Two of these skid trails were covered with litter and logging trash; they did not erode to any measurable extent in the two years observed. The two remaining trails were not protected by litter or trash; these trails eroded an average of 33 cubic feet of soil in the same period. All four trails were located on moderate slopes, ranging from 30 to 45 percent.

Additional advance information is being gathered from reconnaissance investigations of local flood conditions, unusual storms, and large burned areas which create a potential flood source. Of several large burned areas examined in California during the past two years, the most noteworthy in 1951 was the Milk Ranch Creek burn in the Feather River watershed. Soon after the fire, a high-intensity storm struck the freshly burned mountain slopes causing extensive debris damage to power plants, highways, a railroad, and canyon residences. Immediately following the first damaging storm a report was prepared which proposed the following measures to minimize further damage and to rehabilitate the burned watershed: (1) Clean and restore to operation all railroad, highway, and road culverts and drainage structures, (2) install trash racks above existing culverts, (3) construct two debris basins to protect power plants, (4) fall damaged trees along highway and railroad rights-of-way, (5) build contour trenches on bare areas to retard runoff, (6) build waterbreaks or diversions where salvage logging is done, (7) plant trees on contour in the timber sites. Although subsequent storms blanketed the area in snow which lessened the immediate need for emergency treatment, the job of rehabilitation remains to be accomplished.

Six Watersheds Surveyed For Flood-control Measures

Flood control surveys are made, of course, to determine the specific measures needed to reduce flood damages, the costs and benefits of these measures, and the economic feasibility of the flood-control program. In California current assignments of the Station include six watersheds:

Wrightwood on Sheep Creek, Tributary to the Mojave River.--Floods originate on the excessively steep slopes of the San Gabriel Mountains where a great mass of unstable soil has been exposed by past events of obscure origin,

possibly earthquakes and old fires. Mud and boulder flows now occur as a result of rapid snow melt or of heavy rain. The survey showed that because of unstable geologic formations, almost vertical slumps and frequent snowslides, planting vegetation is not a feasible method of controlling these flows. Two other measures were planned to provide safety to the inhabitants of the Wrightwood area. (1) The construction of two debris basins with spillways emptying into concrete lined channels through the developed portions of Wrightwood Village. (2) Public ownership and nonuse of the undeveloped lands subject to overflow. The State Division of Water Resources reviewed the survey report and recommended reconsideration of an alternate proposal which would provide limited protection at lower cost to both Federal and local governments. The report has been submitted to the Secretary of Agriculture for consideration.

San Gabriel and Santa Ana Rivers.--These watersheds each have two distinct problem areas--one the mountains or wild lands, the other the valley agricultural lands. Hence remedial measures for these watersheds logically fall into two broad groups. But downstream flood-control works have been built or are already authorized primarily to control floodwater and sediment from the mountain source area. These structures appear to be so designed or will be so operated as to preclude any immediate need for land treatment in the mountain drainage areas. The structures seem to be adequate for the next 50 years. Yet the rapidly expanding economy stimulated by their protection will be threatened in the future as accelerated erosion continues unchecked and as debris deposition in reservoirs and channels accumulates. The very existence of flood and erosion source areas makes it imperative that ways and means of developing feasible soil stabilization measures in the mountains be investigated thoroughly.

An interim report was therefore prepared for these watersheds. This report recommended measures needed for reduction of flood runoff and erosion on the sloping cultivated lands and the range and pasture lands not protected by existing or authorized flood-control works, and for reduction of local flood damages along minor streams. Recommendations include (1) the improvement of small community channels needed to carry floodwaters from small watersheds and farm runoff disposal systems into the larger channels; (2) the improvement of crop and range lands by land-management practices. The interim report also recommended making investigations in the mountain source areas to

provide the physical and economic bases necessary for development of a feasible watershed-improvement program above the existing and proposed flood-control structures of other Federal and local agencies.

Santa Clara-Ventura Rivers and Calleguas Creek.--This drainage has deteriorated from improper land management on certain cultivated lands, heavy grazing use on the open grass and intermingled brush ranges, and past wildfires which have denuded extensive areas. Deterioration will continue without improvement of the watershed, and this will tend to increase the rate of runoff and erosion and seriously affect the efficient long-time operation of water storage reservoirs under consideration by local interests.

The survey brought out the need for a watershed restoration and management program consisting of such interdependent measures as (1) intensification of fire-prevention and control activities; (2) revegetation of active sediment-producing areas; (3) road-slope stabilization and improvement of surface drainage; (4) structural and vegetative control of active mountain meadow and range gullies; (5) improvement of community waterways in agricultural areas; (6) farm runoff-disposal systems; (7) improvement of irrigation systems; (8) terrace or diversion ditch systems on sloping farm land; (9) seeding to grass certain areas not suited to cultivation; (10) fencing, reseeding, and water developments on national forest ranges. Review committees suggested extensive revisions which are being made so the revised report can be resubmitted to Washington in 1952.

Santa Maria River.--A survey report for this drainage basin was approved by the Secretary of Agriculture in May 1951 and was transmitted to the Federal Inter-Agency River Basin Committee and the State of California for formal review. By December 1951 all such reviews had been completed and comments received from all agencies except the Department of the Army.

The program proposed for treatment of the flood water and sediment source areas in this watershed includes: (1) Acceleration of fire prevention and control measures; (2) public acquisition of scattered privately owned tracts where threat of fire is extremely high; (3) improvement and stabilization of sources of sediment and excessive runoff on range and cultivated areas; and (4) independent channel improvements on tributary streams. The combined effects of all the measures are expected to reduce flood damages about 44